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INDIAN NUCLEAR SOCIETY

INS News Letter

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Contents

From Editor's desk,

It is heartening to observe that the second COVID wave is receding in the country and lockdown restrictions are being eased gradually. It was gratifying to see various sections of society responding spontaneously to tide over the crisis caused by the acute shortage of medical oxygen. Scientific institutions including DAE /BARC are in the forefront to develop new technologies to meet the challenges posed by SARS-CoV-2 and its emerging variants. Intensive efforts are underway to develop / manufacture indigenous vaccines to protect every citizen which seems to be the most reliable way to bring back life to normalcy. Nuclear techniques are being employed world over to mitigate the impact of pandemic. Tsinghua University, together with China General Nuclear Power Corporation (CGN), has applied EB irradiation technology to the sterilization of medical supplies and the treatment of medical waste water.

Last decade witnessed a set back for the nuclear power particularly in the developed countries as an aftermath of Fukushima disaster. However, the challenge of global warming / carbon free world has rekindled the interest of several new entrants like OKLO, X-ENERGY and TETRA-POWER to develop innovative designs of safer / miniaturized reactors which may have better acceptance of public as well as of policy makers due to the reduced costs and diminished challenges of waste management. China has officially begun the construction of the world's first commercial modular small reactor 'Linglong One' in July, 2021 at the Changjiang Nuclear Power Plant in the country's Hainan Province . The first small modular reactor (comprising six interconnected micro reactors producing 462 MWe) is planned to be built on the DOE's desert site west of Idaho Falls at Idaho National Laboratory. Idaho National Laboratory (INL) is also collaborating with NASA to develop a nuclear-powered spacecraft using a uranium-235 reactor core (roughly the size of a paper towel roll) which can travel faster and farther, to Mars and beyond. Nuclear Safety and Security Commission of South Korea has given a conditional approval for the 1,400-megawatt Shin-Hanul No 1, located in the coastal county of Uljin on 9th July, 2021. China's "artificial sun" tokamak has sustained a plasma reaction for a whopping 101 seconds at 120 million degrees Celsius, setting new records in the field of nuclear fusion. The breakthrough could pave the way for a carbon-neutral energy future. Near home, First Pour of Concrete (FPC) of KKNPP-5&6 started on 29th June 2021.

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OBITUARY

25th April 1946 - 23rd May 2021

It is difficult to believe that Dr. Srikumar Banerjee is no more with us. Destiny took him away from us in the wee hours of 23rd May, 2021. INS lost a friend, a philosopher and a guide who could always be trusted to steer the association to achieve any challenging goal. INS fraternity will always miss the affable persona of this great son of India who excelled as a scientist, an institution builder and a very kind human being. Many INS members will remember his brisk morning walks in Anushaktinagar in the company of friends with whom he will exchange his thoughts passionately on a range of subjects varying from music, literature and drama apart from science. He was well versed with the creations of Gurudev Rabindranath Tagore.

Dr. Srikumar Banerjee was born on 25th April, 1946 in Kolkata to Smt. Shanti and Shri Narayana Banerjee. He received his B.Tech. (Metallurgical Engineering) from Indian Institute of Technology, Kharagpur, in 1967. After graduating from the 11th batch of BARC Training School in 1968, he joined the Metallurgy Division, BARC. He obtained his Ph.D. in 1974 from IIT, Kharagpur. He was a senior visiting fellow at University of Sussex Brighton England during 1978-79 and a Humboldt fellow in Max Planck Institute for Metal research (Metalforschung), Stuttgart, Germany during 1979-80. He also served as a visiting faculty in University of Cincinnati and Ohio State University, USA .

Dr. Banerjee was Secretary to Government of India, DAE, and Chairman, Atomic Energy Commission (AEC) from 2009-2012. During his illustrious career spanning over four decades, he served in a number of important positions related to Indian nuclear programme. He was the Director of Materials Group, BARC before taking over as Director, BARC in 2004. He served as a DAE Homi Bhabha Chair Professor at BARC and as Chancellor of Central University of Kashmir, Srinagar after he relinquished office of the Chairman AEC. Dr. Banerjee was the Chancellor of Homi Bhabha National Institute, DAE, Mumbai and Chairman of Board of Research in Nuclear Sciences, DAE when he left us for his heavenly abode.

In recognition of his seminal contribution to the field of metallurgy and materials science, Dr. Banerjee was conferred with many prestigious national and international awards including the INSA Young Scientist Award, Shanti Swaroop Bhatnagar Prize in Engineering Sciences , GD Birla Gold Medal of the Indian Institute of Metals, Alexander von Humboldt Research Award, Prof. Brahm Prakash Memorial Medal from INSA, National Metallurgist Award from Ministry of Steel in 2010, W. J. Kroll Zirconium Medal Award from American Society for Testing Materials (ASTM) and Robert Cahn Memorial Award. He was conferred Doctor of Science (Honoris Causa) degrees from 11 universities and institutions. He was an elected fellow of several national and international academies. Government of India conferred Padma Shri upon Dr. Banerjee in 2005.

INS offers its heartfelt condolences to Smt. Ranjana Banerjee, wife of Dr. Banerjee and Shri Rajarshi Banerjee, son of Dr. Banerjee, and pray that Almighty gives strength to the family to bear this irreparable loss . Dr. Srikumar Banerjee will forever remain in the hearts of all those who had the privilege to come in his contact.

Indian Nuclear Society

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In recent years, Nuclear Medicine has seen spectacular advances in imaging systems (gamma cameras, SPECT-CT, PET-CT) as well as availability of new radiopharmaceuticals for diagnosis and therapy. It is a privilege to share with the members the perspective of one of country's leading practitioner of Nuclear Medicines, Dr Vikram Lele in this issue. Editor of Science India, Dr Debobrat Ghose interviewed Dr Anil Kakodkar on the momentous journey of Deptt. of Atomic Energy since inception. It is indeed a great pleasure to enjoy the glimpses of the events through the eyes of someone who himself was one of the architects of this expedition. In this issue members will find a brief note on the indigenous efforts underway to design Compact High Temperature Reactor principally aimed at producing hydrogen as clean fuel and a review of book entitled "Climate Change and Energy Options for a Sustainable Future" authored by Prof. Dinesh Kumar Srivastava and Prof.V.S.Ramamurthy. There is feature on Nobel Laureate for Medicine, Rosalyn Sussman Yalow who developed Radioimmunoassay Technique which uses radioisotopes as tracers to quickly and precisely measure few parts in a billion of hormones, vitamins, viruses, enzymes, drugs etc. in serum, body fluids and other matrices .

INS continues to make steady progress in pursuing its scientific activities by organizing Webinars and by participating in events related to advancement of Nuclear Science and Technology internationally as well as within the country (Details are given in INS Roundup). One can access all five NLs published since May 2020 on our website www.indiannuclearsociety.com. I urge conscientious members to share the feedback on the contents of NL and help us to make it worthy of their expectations. Solution of the crossword puzzle published in May, 2021 NL is included in this issue along with the names of winners. Everyone is welcome to send the solution of the puzzle of this issue to **insvkmeditor@gmail.com** asap. Names of the winners will be published in the NL issue of Nov., 2021. INS would like to reach out to more professionals interested in the developments of Nuclear World and they are all invited to join the society. Membership form of INS can be downloaded from the website.

Vijay Manchanda

DAE News Brief

Construction of Units 5 and 6 at KKNPP commences

First Pour of Concrete (FPC) of KKNPP-5&6 started on 29th June 2021 at 1100 hours. It is a coincidence that on this day in June 2017, First Pour of Concrete of KKNPP-3&4 was also started. More than 50% of construction of reactors 3 and 4 has been completed. The first two nuclear reactors have so far generated 57 billion units of power. These reactors will place India among the front runners of nuclear energy producing countries,

Oxygen for Medical Purposes - A Life Saving Technology from BARC

Heavy Water Division, Chemical Engineering Group, BARC has indigenously developed advanced compact alkaline water electrolyzer technology for the production of medical oxygen. This system can provide onsite production of medical oxygen at room temperature and supply as per the demand in a continuous mode. This can minimize the issues related to the transportation of cylinders and cryogenic containers of oxygen faced during the pandemic situation prevailed in the country, during April-May, 2021. This technology has been demonstrated at various scales starting from 4 Nlph to 5000 Nlph of oxygen production. Different systems were operated for more than 5000 hours without deterioration in the performance. The system efficiency and purity of oxygen is at par with international standards. The developmental efforts have resulted in the capability and competence of this technology for further scale up to industrial level and the technology has been transferred recently to industry.

Isotope Technology addresses the groundwater sustainability issue in water scarce regions of India

Around 50% population experience high-to-extreme water shortage in the country. This is attributed to disproportionate use of water for agriculture and deficient monsoon. Jal Shakti Abhiyan, a water conservation campaign, was launched by Government of India to accelerate the groundwater recharge in most water-scarce regions of India. Recently, isotope hydrological investigations were carried out by Isotope and Radiation

Application Division, BARC in three water scarce regions of Srikakulam district of Andhra Pradesh to quantify the contribution of surface water bodies (tanks) to groundwater. Isotope data suggested that groundwater recharge is mainly through fracture flows and the surface water bodies contribute up to 60% of the total recharge. The outcome of this investigation will help in planning the water conservation measures in an efficient and economical manner.

Multifunctional superabsorbent cotton for oil-water separation

A multifunctional cotton having super-hydrophobic and super-oleophilic properties was developed by Isotope and Radiation Application Division, BARC using electron beam radiation processing for efficient separation of toxic organic liquids and oils present is dischargeable aqueous streams . The commercially available cotton was immersed in an aqueous-ethanol (10% water and 90% ethanol) solution of a monomer. After 3-4 hours the sample was irradiated with an electron beam , dried and used . The process modifies surface energy and molecular level topography of the cotton fibres by attaching long chain hydrocarbon molecules. Hence, the modified cotton was found to absorb toxic organic oily liquids from water at around 30 gm/gm ratio. The absorbed organic compound can be separated by squeezing the cotton and the superabsorbent can be reused more than 50 times. The cotton based superabsorbent is physically and chemically robust, high temperature resistant and biodegradable. An Indian patent has been granted on this product and the technology has been transferred to a private company.

Specialty Materials produced by Heavy Water Board

O-18 Enriched Water

O-18 enriched water, a specialty material finds wide spectrum of applications in the field of nuclear medicine and biomedical research. The requirement is at 10 % IP water for studies in the area of energy deficit during exposure to extreme climatic conditions that results in loss of body mass energy, and at 95 % IP water for carrying out PET scanning for detection and staging of malignancies / cancer in patients. HWB in a short span of 10 years has designed, developed and successfully deployed the technology on industrial scale for the production of O-18.The facility at HWP Manuguru, Telangana can produce 100 kg/hr of 10% IP and 10 kg/hr of 95.5% IP. Marketing of O-18 enriched water is proposed to be done by BRIT for healthcare applications (PET scanning).

Deuterium Depleted Water

After enriching natural river water containing 150 ppm to heavy water, the effluent leaves the plant at low deuterium concentrations (125 ppm). Deuterium Depleted Water (DDW) of 25 ppm to 125 ppm, has wide applications in the field of anti-cancer/ tumor, anti- diabetic, nonspecific immune defense of the body and anti-ageing etc. HWB has ongoing program in association with ATREC, DAE for investigating its potential as an adjuvant in the treatment of cancer. HWB can also produce customized DDW of concentrations varying in the range 10ppm to 90 ppm. HWB has executed an order of 90 MT of 125 PPM DDW for an Indian company with more to follow.

Calix Crown-6 (CC-6)

Calix Crown-6 is a specialty organic solvent (1,3-Di-n-octyloxycalix[4]arene-crown-6 (CC- 6)) is required for the selective separation of ^{137}Cs from the high level liquid waste of spent fuel and using it for Cesium pencils (at WIP, Trombay) for blood irradiation applications. The process for the synthesis of this special organic solvent was developed by BARC at lab scale. Scaling up of its production was taken up at HWP, Talcher based on the inputs from BARC. The synthesis of CC-6 involves preparation of Pentaethylene Glycol di-tosylate (PEGdiTS) and then reaction of PEGdiTS with Calix-3 to get CC-6. Both the steps have been successfully carried out at HWP, Talcher, and trial runs yielded 2.5 Kg with 65% yield, which meets the product specifications. The product is currently utilized in the Cesium pencils production unit and further scale up production of 10 kg batch is in progress.

B-10 enriched Boron Carbide (B_4C)

67% I.P. B_4C powder produced at HWP-Manuguru in the past was utilized for making B_4C pellets required for the first and second core of PFBR BHAVINI. Recently, as per the requirement of IGCAR of maintaining minimum shutdown margin with additional SAs and also utilizing the partially burnt SAs available in the core, 50% I.P. B_4C pellets for control rod applications in FBTR have been produced at HWP, Manuguru. The 50% I.P. B_4C pellets were handed over by GM, HWP(M) to CE, NFC on 22nd April 2021 in the presence of Chairman AEC & Secretary DAE and other dignitaries.

Nuclear Grade Sodium

HWB has commenced project activities for setting up of industrial scale nuclear grade (NG) Sodium Metal production facility (600 MTPA) based on 24 kA close cell design developed at HWP, Baroda. In addition, a bench scale purification facility (400 Kg/batch) was designed, installed and commissioned for the purification of industrial grade sodium to nuclear grade (NG) sodium as per the technical specifications. It is worth mentioning that the industrial scale facility for the production of nuclear grade sodium metal is a first of a kind facility in the country. IGCAR has confirmed that the quality of Sodium Metal (3T) produced at HWP Baroda is meeting the technical specifications.

Compiled by Vijay Manchanda

Nuclear Medicine: A Scintillating Journey

Abstract

Nuclear Medicine, which uses radioisotope products called radiopharmaceuticals in the diagnosis and management of human disease, has made tremendous advances over the last several years. Spectacular advances in imaging systems (gamma cameras, SPECT-CT, PET-CT, PET-MR) and availability of several new radiopharmaceuticals (RP) for diagnosis and therapy have put this specialty firmly on a rising path. RPs for diagnostic imaging are largely based on ^{99m}Tc, ^{18}F, ^{68}Ga (2-15 mCi dose); and for therapy ^{131}I, ^{177}Lu, ^{90}Y (100s of mCi dose) are used. Nuclear Medicine is now firmly established in cancer diagnosis and therapy, in management of neurological and heart disorders (apart from its continuing important roles in other specific areas, for example, management of certain types of thyroid patients).

Introduction

Human disease is caused by disorders of structure and function of various organs. Diseases caused by disorders of structure are exemplified by: tumors (cancer), where unchecked growth by rogue cells leads to deformation and destruction of normal tissue; heart attacks and brain stroke, where lack of blood supply leads to destruction of normal functioning heart and brain cells; congenital diseases, where defective genes cause malformed organs with abnormal structure. All these structural diseases are very nicely studied by anatomical imaging modalities like Ultrasound, CT scans and MRI with exquisite anatomical detail possible to be seen in 3 dimensions.

Disordered function, however, may invariably precede disordered structure by several months or even years. Some diseases are characterized by predominantly disordered function, with structure of the organs remaining relatively intact or only mildly altered. Examples of such disorders include psychiatric illnesses like schizophrenia and depression, Parkinson's disease, Alzheimer's disease in early stages, several endocrine diseases like Diabetes Mellitus. In many of these diseases, abnormal brain signaling, and neurotransmitter and receptor dysfunction lead to physiological disturbances.

Nuclear Medicine (NM), due to its inherent ability to (non-invasively) study physiological processes in the body and their alterations in disease, with the help of appropriate radiotracers, plays a unique role in the diagnosis and management of several of the above-mentioned disorders.

The ability to study processes like tissue perfusion (blood-flow), metabolism of various substrates like glucose, amino acids, various types of receptors involved in signaling pathways, markers expressed on tumor cells, etc. makes Nuclear Medicine a very powerful and often unique tool.

The journey of organ imaging from rectilinear scanners to gamma cameras, to single, dual, triple head imaging systems, SPECT (Single Photon Emission Computed Tomography), PET (Positron Emission Tomography) and now hybrid unit, SPECT-CT, PET-CT and PET-MR, which combines anatomical imaging and nuclear imaging in one system, has been spectacular and has provided a very powerful tool to study diseases. Whole body PET scans are now possible in a minute with the latest multi-detector scanners.

Reading the mind

One of the earliest uses of nuclear medicine was in studying the brain perfusion. Tracers like ^{99m}Tc-

HMPAO and ^{99m}Tc-ECD gave excellent images of brain perfusion. The arrival of PET-CT technology and availability of ^{18}F-FDG (Fluoro Deoxy Glucose) from medical cyclotron (MC) facilities permitted high resolution metabolic images of brain to be acquired. The brain uses glucose as its primary source of energy. Fluoro Deoxy Glucose labelled with ^{18}F (a positron emitter) is a glucose analogue which is taken up by the brain cells just like glucose but not metabolized further. Its distribution in the brain gives a map of brain regions which are metabolically and functionally active. In Alzheimer's disease, which is characterized by memory loss, typical patterns of reduced metabolism are observed in specific areas of the brain at a time when CT and MRI show no abnormality **(Fig.1**). Hence in a person with memory loss, an abnormal brain PET raises the red flag about impending Alzheimer's disease (AD), while a normal scan can reassure the patient that the memory loss is nothing serious and could be due to normal ageing. Ability to unequivocally show the progression of AD is also helpful to the pharma industry in their expensive drug development efforts.

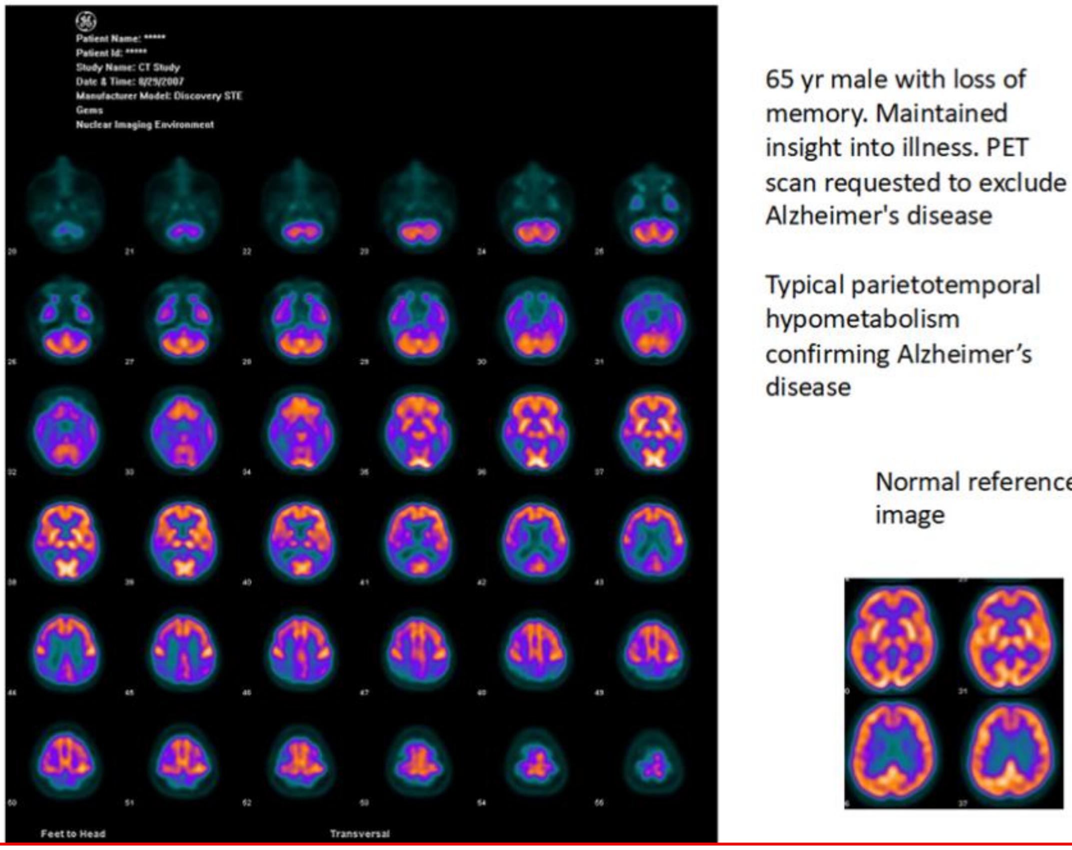

Fig. 1: Illustrative PET images of brain in a patient with memory loss and in a normal case

We are able now to image various types of receptors in the brain such as dopamine, serotonin, acetylcholine, opiate, benzodiazepine and study their distribution in health and disease. Parkinson's disease can be easily diagnosed now with ^{18}F-DOPA (amino acid derivative) PET scan; ^{99m}Tc-TRODAT SPECT scan is also greatly helping neurologists. The diagnosis of Parkinson's disease may be erroneous in as many as 20% of patients based on clinical examination alone and the use of nuclear scans can prevent unnecessary treatment being started on such patients. With the help of specific amino acid tracers like ^{18}F-FET (fluoro-ethyl-tyrosine), brain tumors can be easily detected and differentiated from necrotic tissue present after treatment, when recurrence is suspected.

Matters of the heart

Heart attacks kill thousands of Indians every year. Preventions with life-style modifications and control of risk factors like diabetes, hypertension, smoking, cholesterol, obesity and stress form the mainstay in management. Once diagnosed with ischemic/ coronary artery disease, the paradigm so far has been heavily tilted in favour of interventions like angioplasty, stenting and bypass surgery - the "oculostenotic reflex" … see a coronary stenosis in a patient, open up the stenosis! Current evidence from several trials like the COURAGE and FAME trial have proven beyond doubt that optimal medical management is as good as interventional management, in patients with ischemic heart disease, if physiological information is used in clinical management decisions, rather than going by anatomical information alone (however compelling they may be). Use of nuclear medicine scans like the myocardial perfusion SPECT scan with ^{99m}Tc-MIBI/ Tetrofosmin or ^{201}TlCl, or myocardial PET scans with Rubidium-82 or ^{13}N-Ammonia, can identify patients, who have a high burden of ischemia and who will benefit from interventions, rather than by medical therapy alone. Thus, lot of unnecessary angioplasties / stenting / by-pass surgeries would be avoided in the objectively selected (that is, based on the findings of a well-performed myocardial perfusion study) group of patients (otherwise to be conservatively listed for undergoing interventional procedures). A patient with a normal myocardial perfusion scan can be safely managed with aggressive medical therapy, even if the coronary angiography shows narrowing in all the arteries. There is also additional scope of NM procedures to contribute in cardiac care. Its capability of superior quantification of perfusion parameters can be helpful to project more objectively the prognostic outcome.

Fighting cancer

The major utility of nuclear medicine has been in the fight against cancer. Nuclear scans, especially PET-CT scans, are used nowadays at every stage of cancer management, from diagnosis, staging of disease (mapping out the extent of spread - metastasis), gauging response to therapy, and detecting recurrence after successful therapy. Since cancer cells are rapidly multiplying and need energy, they are greedy for glucose. They lap up ^{18}F-FDG several fold higher than normal tissues and this forms the basis of using FDG in cancer diagnosis. The tumor sites stand out as “hot spots” on ^{18}F-FDG PET-CT scan. Objective findings of PET scan can help identify the extent of efficacy of on-going therapy and also enable need-based, timely mid-course alteration of therapy regimen. Some tumors however are not metabolically very active and are slow growing. Examples of such tumors are Neuroendocrine Tumors (NET), prostate cancer and some mucin secreting cancers of breasts and lung and gastrointestinal tract. These can be missed on a routine ^{18}F-FDG PET scan. These tumors express other markers on their surface, which can be visualised by PET imaging with well-designed radiopharmaceuticals and detected easily. Neuroendocrine tumors express somatostatin receptors which can be targeted for PET imaging with an appropriate radiolabelled peptide, namely, ^{68}Ga-DOTATATE. Prostate cancers express PSMA (Prostate Specific Membrane Antigen), which can be similarly visualised by PET with suitable binder molecule labelled with ^{68}Ga or ^{18}F - denoted as ^{68}Ga/^{18}F-PSMA binder ligand. These PET scans are now the gold standard for NET diagnosis and prostate cancer staging.

Many cancers have fibroblasts in the stroma. These Cancer Associated Fibroblasts (CAF) express Fibroblast Activation Protein (FAP), which can be visualised with ^{68}Ga or ^{18}F labelled RP. ^{68}Ga-FAPI promises to be the new revolutionary radiopharmaceutical for cancer diagnosis, which will possibly replace ^{18}F-FDG in most cancer diagnostic indications. It offers also practical advantages of not requiring 6 hours fasting and sugar control of patients (^{18}F-FDG PET scan requires) and scope for early imaging at 10 minutes post-injection, rather than an hour after injection.

Theranostics is a new approach in Nuclear Medicine where diagnostic and therapeutic pairs of RPs are used with the same binder (targeting) molecule for both diagnosis and therapy of cancer. For example, ^{68}Ga-DOTATATE is used to diagnose NET. Once the presence and extent of disease has been mapped on the PET scan, ^{177}Lu-DOTATATE (or ^{90}Y-DOTATATE) is used as a therapeutic agent, which selectively targets and destroys all the lesions detected on the ^{68}Ga-DOTATATE scan. ^{177}Lu is a beta emitter of medium energy which is lethal for cells. ^{90}Y is another similar beta emitter and of higher energy, suitable for larger tumors requiring deeper penetration.

Similar theranostic pair is ^{68}Ga-PSMA binder ligand and ^{177}Lu or ^{225}Ac-PSMA binder ligand for prostate cancer. Another new pair is ^{68}Ga-FAPI and ^{177}Lu/^{225}Ac-FAPI for all tumors which are positive on ^{68}Ga-FAPI PET scans.

Role of BARC and BRIT

The Nuclear Medicine community in India owes a debt of gratitude to BARC and BRIT for making available all the routine radiopharmaceuticals, cold kits and ^{99m}Tc generators and Iodine-131 at affordable cost. This has made Nuclear Medicine possible in most centers in the country. Availability of ^{177}Lu at a very reasonable cost and in prelabelled ready to use form has been a boon for our patients. It is hoped that in future the frequency of supply will be more reliable and that carrier-free ^{177}Lu may be also made available. ^{68}Ga use is largely dependent on imports of ^{68}Ge-^{68}Ga generators. Since, scope for direct production of ^{68}Ga in medical cyclotrons (MC) by $^{68}Zn(p,n)$ reaction has been established (also demonstrated by BRIT at Kolkata), timely support for development and adoption of this technology by interested MC centres will be worth considering.

It is the wish list of the Indian Nuclear Medicine community to have the alpha emitter ^{225}Ac made available in India indigenously. There is tremendous potential for using ^{225}Ac-DOATATE/PSMA/FAPI in therapy of different cancers. Therefore, exploring all possible legacy sources for stockpiling ^{229}Th, precursor of ^{225}Ac, as well as developing indigenous capability to produce ^{225}Ac in cyclotron (by p,2n reaction on Radium-226 target at the cyclotron facility at Kolkata) are strategies to be given priority consideration. If ^{90}Y and ^{225}Ac are made indigenously available to NM centres (in addition to ^{177}Lu, ^{131}I), then India will be at the forefront in the therapy arena. It is well within the power and expertise of the Indian Atomic Energy Establishment and their leaders to make this a reality.

Dr. Vikram R. Lele

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Director, Department of Nuclear Medicine & PET-CT, Jaslok Hospital & Research Center, Mumbai. Dr. Lele is a Fellow in Nuclear Medicine of The Johns Hopkins Medical Institutions, USA and Germany. He is a recipient of the Homi Bhabha Memorial Oration award of the Society of Nuclear Medicine, India (SNMI). He is the Past President of the Association of Nuclear Medicine Physicians of India (ANMPI) and Nuclear Cardiological Society of India (NCSI)

Reviewer: Dr. N. Ramamoorthy, Former Head of the Radiopharmaceuticals Programme of BARC and BRIT

Nuclear Tests Proved Game Changer in India's Global Identity'

(Dr. Anil Kakodkar, Former Chairman of Atomic Energy Commission of India in Conversation with Debobrat Ghose, Science India)

At the helm of India's nuclear research programme for several decades , Dr Anil Kakodkar, former chairman of Atomic Energy Commission and former director of Bhabha Atomic Research Centre, has seen it grow despite infinite challenges to reach the present stage when India has a fleet of 22 operational nuclear power units with nine under construction and 12 more planned. Though nuclear energy production continues to contribute a meagre, less than 2% to the country's total energy requirement, Dr Kakodkar feels that nuclear energy is the most feasible solution for India to achieve energy independence.

He speaks to Science India *at length about the current state of India's nuclear research programme, why it needs to be accelerated, how nuclear technology can improve the lives of people in rural India, why the country continues to be outside the influential NSG, and more. Excerpts:*

With two nuclear tests carried out in 1974 and 1998, India entered the elite club of nuclear-capable states. It was a moment of pride for Indians. Did the tests help in changing the world's perception about the nation, the perception of our adversaries, from viewing us as a soft target to a strong nuclear power?

Most certainly. Look at the general perception of people before and after the tests. Post-test, there was a much larger acceptance of India as a responsible and strong country, with advanced technologies. Respect for India and Indian products grew, significantly improving exports as well.

A classic example is access to technology like computer chips. In those days, at most chips like 286, 386 or 486 were available in India but high-end chips and products in which these chips were embedded were not available. But after these tests, better equipment became available. It made a lot of difference in general.

Specifically, about nuclear tests, of course, it ena-

Then President of India, Pratibha Devisingh Patil presenting the Padma Vibhushan toDr Kakodkar on March 31, 2009

bled the country to declare itself as a de facto nuclear state, but more than that, I have seen that even before the 1998 test, there was tremendous respect for India's nuclear technology. In those days, several things were not permissible, yet we used to have interactions with advanced countries.

Post-1998 test, we got exemptions from NSG (Nuclear Suppliers Group) — a big change in perception again. A lot of nuclear commerce opened for India but certain elements were still not open. But that's true even for two allies — while certain things are allowed, some are not.

What is India's roadmap on nuclear energy programme and where do we stand today?

Initially after 1974, the challenge was to develop nuclear power technology in spite of embargos. We did it and made reactors, which worked very well. While we solved the technology problem, there was still the fuel problem — the uranium needed to fuel the reactors in the first stage of the power programme. There was a shortage of uranium in the country at that time.

After exemptions from NSG, we started getting uranium from outside. Our reactors started working at near maximum possible capacity. We simultaneously increased our domestic exploration of uranium. Today, our uranium reserves are three-four times the past. Now, the challenge was to implement the capacity addition very fast.

As per our three-stage programme, we started with uranium reactors but ultimately, we have to reach the thorium reactors

That is a multiple technology development related to reactors as well as nuclear recycle technology. The fast reactor has to have a concurrently running recycle technology, which has to be proven on a commercial scale. And then the reactors and recycle plants for thorium.

Just as we went with technology development for heavy water reactors (HWRs), or uranium reactors, we have to go for development in so many other technologies — fast reactor technology, thorium technology, fast reactor recycle technology and thorium recycle technology. There were some important sub-divisions within these categories.

Climate change has become very important and that requires non-fossil electricity generation. We lay a lot of emphasis on renewable energy — solar, wind, etc — but most of these are variable in nature. The only substantial non-fossil energy source that is not variable in nature, acts like a base load and can give steady generation of electricity, is nuclear.

The total potential of bio-energy is not small but not large enough to compare with our growing needs. In that context, three major sources to concentrate on are solar, wind (both variable) and for good result at optimum cost to consumer, nuclear energy source.

I think realizing sizeable electricity generation capacity in tune with the decarbonized world has become urgent. The Intergovernmental Panel on Climate Change (IPCC) says that by 2030, emission should be reduced by 45% and by 2050, it should be net zero.

In this context, we must focus on rapid ramp up of nuclear generation capacity, by leveraging currently known technologies, even though the three-stage program development still remains a long-term goal as thorium is a vast energy source.

How can technology help in ameliorating the

lives of people, especially in rural India, where basic infrastructure is still a dream for many?

This is an important question. First, electricity is important both in urban and rural India. Although electricity grid has reached everywhere, it doesn't mean you are able to supply electricity everywhere as our grids are still weak. In this context, nuclear energy is very important

There is a kind of perception that you can generate all your requirement using solar and wind energy, and variability can be addressed by deploying battery capacity. This is not a cost-effective solution.

Studies conducted at MIT and other institutes have shown that a zero-emission electricity system comprising a mix of only variable, renewable energy sources like solar and wind — increases the tariff for consumers two to four times due to various factors related to transmission and distribution as well as system related costs including fuller asset utilization.

Since we are also heading towards zero carbon emission, a model has to be worked out that takes care of all these aspects at minimum cost to the consumer. Theoretically, it is possible to generate all necessary electricity by wind and solar energy in a decarbonized world but it will cost us several times our GDP.

For rural India, quality of power is very important and there is a cost to that quality of power. So, if there is a significant fraction of nuclear energy, then you get a good quality of power at optimum cost. This is one way of improving the lives of people.

The other part is utilizing nuclear technology to improve agriculture such as in the quality of seeds. A good variety of oilseeds and pulses in India come from nuclear mutants developed at BARC (Bhabha Atomic Research Centre) and several agricultural universities. Radiation is used in other fields such as in preservation of perishable food items, in healthcare, medical products, cancer treatment, sewage treatment, etc.

In general, best technology is not always available for asking. Investing in technology is very important but it also has to be appropriate to the needs of the country. For example, Artificial Intelligence solutions, a prime technology today, is coming out of products developed abroad. It may or may not be appropriate for rural India as the data set from foreign cultures may have an in-built bias.

Power production in India is through nuclear fission only. Are we pursuing power generation through fusion?

Chairman of Atomic Energy Commission Anil Kakodkar signs agreement on civil nuclear cooperation with French Foreign Minister Bernard Kouchner on September 30, 2008, in the presence of Manmohan Singh and Nicolas Sarkozy

Surely, as I said for addressing the climate change concern that has become an urgent issue, we should enhance capacity through available technologies, but there is merit to continue work on a three-stage nuclear programme — which is still fission.

That is because thorium has a large energy potential. Similarly, fusion constitutes even a larger energy potential. Energy is going to be a perpetual requirement for sustaining humanity. Unfortunately, we're still not there and are still working on its development. India is an equal partner in ITER project — the largest international project on fusion energy. India is manufacturing and supplying some of the largest components for the ITER programme.

The Institute for Plasma Research in Gandhinagar and a few others are working on our domestic programme. Electricity generation from fusion is still sometime away. Fusion may not be able to contribute by 2050 but that doesn't mean it's not important, because fusion energy potential is large and human beings will survive far beyond 2050.

Dr Homi J Bhabha had mentioned three stages of Indian nuclear programme —- Uranium-fuelled HWRs; Plutonium-fuelled Fast Breeder Reactors; and Advanced Thorium-based Reactors. Where is India in this plan today and when can the nation be Atmanirbhar in energy by using our available thorium resources?

Uranium fueled HWRs are already being commercially deployed. Commercial prototype of 500 MWe FBR is under commissioning. On a smaller scale we have done everything connected to thorium — we have irradiated thorium; separated Uranium-233; and we have created a mini reactor out of U-233, which is called 'Kamini' and has been running in Kalpakkam for more than two decades.

But that doesn't amount to creating a large thorium-based power reactor. We have completed the design and development of an advanced HWR which is a 300-megawatt system producing two-thirds of its energy from thorium. And this was developed after the Chernobyl incident. The idea was to incorporate several safety features to rule out the possibility of any impact in the public domain, unlike in the case of Chernobyl and Fukushima.

Now, it is upon the government to decide and construct one prototype as the development has reached a mature level. But it's not enough. Ultimately, in the third stage, you may require yet another kind of thorium reactor and most probably, it will be a molten salt reactor. It will give much better performance as far as thorium is concerned, particularly in the context of self-sufficiency. Work on thorium has to go on. We have done a lot, we are ready to scale it up, also, more is to be done in a high temperature reactor where also thorium can play a big role.

You have played key roles in several high-tech projects from designing, construction to implementation on ground like indigenous Dhruva reactor, nuclear submarine, etc. Is India capable of building more indigenous devices in future?

Yes, surely. We shouldn't undermine the capability of Indian youth. Dr Bhabha used to say, the problem is that many times people are hesitant in posing a challenge. Besides posing challenges, you find people who are ready to take that challenge and then support them well. That's how so many things got realized. See the start-up culture, how it is rising. Sky's the limit. That's the meaning of demographic dividend — the number of people who can accomplish things at the global level. India has this capability, and the leadership should create the right conditions, provide challenge and support.

Despite following international agreements related to atomic energy and with no embargo unlike in the past, India is still not a part of the Nuclear Suppliers Group (NSG). Why so and will it impact India's growth?

It would have an impact. Now, we have exemptions from NSG, so we are able to get material and technology and we are also talking about setting up reactors, such as in Kudankulam, in cooperation with other countries. But the important thing is that the rules of NSG are set by NSG themselves. If you are not a member of the group, your interests may be in jeopardy. On the other hand, if you are a part of the group, then you are assured of your interests remaining protected. In terms of qualifications necessary for NSG membership, we have it and meet all criteria. India has been identified as a responsible country with advanced nuclear technology. We are exporting heavy water and other nuclear technology items, so we should legitimately be a part of NSG.

We must be more ambitious. India is the only country which is not exporting reactors unlike other countries that have developed them. Despite hurdles, we should export on a large scale, so that the NSG feels the need to take us in the group. Diplomacy must be at work at all times and look for opportune moment; but also create conditions where the world opinion gets translated in our favour.

How will nuclear energy impact India's future on issues such as energy security, climate change and zero carbon footprint?

To some extent, I have elaborated that earlier. Today the strongest feature of our energy security is coal — in terms of quantity, domestic availability, etc. We also consume a lot of oil that is mostly imported. So, there is significant vulnerability to our energy security and then we have to move towards zero carbon footprint. Nuclear energy is a huge resource. We import uranium but we've one of the largest thorium reserves in the world. If we take thorium technology to its full maturity, we can address energy security issues in full, without significant carbon footprint. Our pursuing three-stage nuclear programme is actually very important. Now, what if we don't do this? First, our vulnerability to challenges of energy security will go up, and electricity, if derived from solar and wind power, will become more expensive. Nuclear energy is extremely important. There is a perception issue about accidents and safety associated with nuclear plants. But in terms of risk per unit of electricity produced, nuclear energy is the best compared to all other energy sources.

How can research in the nuclear field in IITs and other premier institutions be converted into industrial applications?

To some extent, it has already happened as in the case of HWR. We've done large megawatt scale experiments for the design of HWRs. A lot of research and work have been done on a large-scale at IIT Bombay and BARC. The IITs are doing a great job on industry usable development.

With India's nuclear doctrine based on 'No first use policy', are we prepared to give a quick and befitting reply in case of a nuclear attack?

Yes. Though I am not a part of that system now, what I understand is that India's nuclear doctrine, which is in public domain, says 'no first use'. But part of the same policy also says, should there be an attack on India using weapons of mass destruction, then India will retaliate swiftly to create unacceptable damage to the adversary. The two have to be seen together.

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Rosalyn Sussman Yalow : A Nobel Laureate for Medicine

In 1977, Rosalyn Yalow became the second woman to win the Nobel Prize in Medicine (shared with two others) for co-developing Radio-immunoassay (RIA) with Solomon Berson in the 1950s. RIA is a revolutionary technique that uses radioactive isotopes as tracers to quickly and precisely measure very minute concentrations, few parts in a billion (10^{-9} to 10^{-12} M) of hormones, vitamins, viruses, enzymes, drugs, and literally hundreds of substances/analytes in serum, body fluids and other matrices without pre-purification. RIA can be termed as the most significant advancement of medicine in the twentieth century, which has given a new dimension to clinical medicine and to investigative/laboratory medicine as well. The technique "brought a revolution in biological and medical research," the Karolinska Institute in Sweden said in awarding Dr. Yalow, along with Andrew V. Schally, M.D., Ph.D., and Roger Guillemin, M.D., Ph.D., the Nobel Prize for Medicine in 1977. (Dr. Berson would have shared the prize but he died in 1972, and the Nobel Prize is not given posthumously).

Rosalyn Sussman was born on July 19, 1921 in New York City, where she always resided, studied and worked except for a few years when as a graduate student she pursued her PhD at the University of Illinois at Champaign-Urbana. She went to Walton High School, Bronx, New York City, where she was keenly interested in chemistry, but this changed to physics when she attended Hunter College. Those were the years when, even in the USA, education of women was lagging behind that of men, and showed Rosalyn's determination to study. Her mother hoped she would become a schoolteacher, which most college educated women at that time did. Instead, Yalow decided to study physics and in her own words, "In the late '30's when I was in college, physics, and in particular nuclear physics, was the most exciting field in the world. It seemed as if every major experiment brought a Nobel Prize.

As a Junior at college at Columbia University, Rosalyn attended a colloquium given by Enrico Fermi in January 1939 on the newly discovered nuclear fission; which had resulted not only in the terror and threat of nuclear warfare but also in the ready availability of radioisotopes for medical investigation and in hosts of other peaceful applications." Hence, she was very keen on pursuing physics as a grad student, but she was very aware of the limited opportunities of scholarship for a woman (and a Jew). She had a knowledge of typing and stenography and worked part-time with a professor in Colombia University, hoping to get an entry this way to be a grad-student. Encouraged by her physics professors at Hunter College, she applied to many universities and was overjoyed to get an offer of a teaching assistantship in physics at the University of Illinois and joined there in fall 1941. She was the only lady in the Faculty of the College of Engineering and the first woman since 1917. It was there she met Aaron Yalow, whom she married in 1943.

Left: Dr. Rosalyn Yalow at her Bronx Veterans Administration Hospital, Oct. 13, 1977, after learning she had won the Nobel Prize. Right: With the Nobel Prize medal

The USA got involved in the Second World War after the bombing of Pearl Harbour in December 1941, and many of her male colleagues had to leave to join the war effort and secret research projects. She was faculty to the many army and navy personnel sent to the campus for training. She completed her PhD in 1945 guided by Dr. Maurice Goldhaber, who later became Director of Brookhaven National Laboratories. Since her research was in nuclear physics, she became skilled in making and using apparatus for the measurement of radioactive substances, which would come handy later. On completing her thesis, she returned to New York and worked for a while as an assistant engineer at Federal Telecommunications Laboratory, a research laboratory for International Telephone and Telegraph Corporation, the only woman engineer. Subsequently, she joined as faculty at Hunters College and was a part-time consultant at Bronx Veterans Administration Hospital with Dr. Roswit. She equipped and developed the Radioisotope Service and started research projects together with Dr. Roswit and other physicians in the hospital in a number of clinical fields that resulted in several publications.

In 1950, Rosalyn Yalow worked full-time at Bronx VA and at this time Dr. Solomon Berson, an internal medicine clinician joined Bronx VA. The distinguished phase of her career with Berson began with the applications of radioactive isotopes in healthcare. Their first investigations together were in the application of radioisotopes in blood volume determination, clinical diagnosis of thyroid diseases and the kinetics of iodine metabolism. They extended their studies to the metabolism of plasma and serum proteins by labeling them with I-131 and observing their retention in blood and the body compartment (tissue, muscle, bone etc.). All their studies were novel at that time and provided a great deal of information on human physiology. Next, they applied these techniques to hormones, and chose insulin as it was available in a highly purified form. Using (I-131)-insulin they found that in many diabetic patients on insulin therapy, the insulin clearance rates were slower than in normal subjects. This led them to identify that the diabetic subjects receiving insulin produced antibodies to them, which bound the insulin in circulation and made the insulin ineffective. One should remember that those were the days when genetically engineered human insulin was not available, and patients were administered insulin isolated from pancreas of either cattle or pigs. Bovine-insulin is different from human by two amino acids, while porcine differs by one. Subjects receiving bovine insulin more often produced antibodies compared to those who received porcine insulin.

Berson and Yalow soon realized their serendipitous discovery is a promising tool for measuring circulating insulin. They had to put in more years of work to bring their concept into a practical reality to measure plasma insulin in man. They did not patent their technique as they realized its potential in human healthcare. Their results were published in Nature in 1959 and, thus, the era of radioimmunoassay (RIA) can be said to have begun.

Principle of RIA is based on the fact that an animal's immune system hosts an antibody response when it comes across a foreign (non-self) antigen. The antibodies are uniquely specific to the antigen and will bind to it only, excluding other molecules in the milieu. Hence, specific antibodies to any analyte (hormone, protein, peptide, drug etc.), can be produced using it as an antigen to immunize a laboratory animal, usually a rabbit, guinea pig or mouse. Once immunized, the animal will develop the specific antibodies in its blood. Blood is drawn from the animal and the serum, which contains the antibodies, is separated and used. A pure preparation of the analyte to be measured is labeled with a radioactive isotope, usually I-125, because of its unique decay properties. Fixed amount of the (I-125)-analyte (Ag^*) and a fixed amount of the antibody (Ab) are reacted (incubated) with known concentrations of the analyte (Ag) to generate a dose-response standard curve. Patients' samples in which the analyte concentration is to be measured are also reacted with the same fixed concentration of Ag^* and Ab. After incubating the reaction mixture, a suitable technique is used to separate the analyte-antibody bound complex (Ag-Ab) and (Ag^*-Ab) from the unreacted Ag^* and Ag. The radioactivity in the bound fraction is measured in a radioactivity counter and analyte concentration interpolated from the dose response graph mentioned above.

RIA is now used to measure hundreds of substances of biologic interest in thousands of laboratories all over the world. Thyroid disorders, dwarfism in children are some of the diseases treated with information from RIA. Clinical medicine, in particular endocrinology and oncology would not be as advanced as it is today without the ground breaking work of Berson and Yalow. Although RIA and its non-competitive variant immune radiometric assay (IRMA) are little used nowadays, but RIA is the shoulders on which the non-isotopic immunoassays grew which are widely used commercially, like enzyme-labeled assays, chemiluminescence assays, fluorescence assays. **The rapid-antigen-test (RAT) used for covid-19 tests is a non-isotopic immunoassay.**

Berson and Yalow trained many young scientists from all over the world in their laboratory at Bronx VA. They referred to them as 'professional children' and enjoyed mentoring them. **Late Dr. A.M. Samuel, former Director, Biosciences Group , BARC was one of them. Dr. Yalow visited RMC soon after receiving her Nobel Prize in December 1977 and gave a talk in the CC auditorium, which I attended, little knowing that RIA would be a part of my career in BARC. Dr. Berson had visited RMC as a visiting scientist in 1970 and trained staff in RIA of insulin.**

The sudden passing away of Dr. Berson in 1972 was a shock to Dr. Yalow. They were among the probables for a Nobel Prize in Medicine. Dr. Yalow named her lab Solomon A. Berson Research Laboratory in his memory. In all publications till his death, Berson was the first author. This meant that Dr. Yalow had to prove to the world that she was an equal contributor, which she aptly did with subsequently published work.

For years, Dr. Yalow faced criticism from women at work as being over ambitious, but she never quit nor turned her back on other young women, if she believed they had the potential to become real scientists. She never became an advocate for women's organizations in the field of science. She was even quoted as saying, "It bothers me that there are now organizations for women in science, which means they think they have to be treated differently from the men. I don't approve." Although girls and young women found a role model in her after she won her Nobel, Yalow was not a champion for improving women's treatment or representation in science.

Apart from the Nobel Prize, Dr. Yalow was a member of the National Academy of Sciences. She received many honors including among others: Albert Lasker Basic Medical Research Award; A. Cressy Morrison Award in Natural Sciences of the N.Y. Academy of Sciences; Scientific Achievement Award of the American Medical Association; Koch Award of the Endocrine Society; Gairdner Foundation International Award; American College of Physicians Award for distinguished contributions in science as related to medicine; Eli Lilly Award of the American Diabetes Association; First William S. Middleton Medical Research Award of the VA and five Honorary Doctorates.

At her death, on May 30, 2011, she was senior medical investigator emeritus at the James J. Peters Veterans Affairs Medical Center, Bronx, and the Solomon A. Berson distinguished Professor-at-large at Mount Sinai School of Medicine in New York City. She was predeceased by her husband (1972), and survived by two children, Benjamin and Elanna, and two grandchildren.

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Brief overview of the new reactor designs in BARC

Development of new reactors and associated technologies in BARC is aimed towards making our country self-reliant for our long-term energy requirements. It is well known that currently our transport sector is heavily dependent on the imported crude oil and gas. Their use also has greenhouse gas emissions and other environmental concerns. Nuclear energy assisted production of hydrogen, by way of splitting water at high temperature, is a long -term solution for providing energy security to our country in this direction. Development of high temperature reactors is aimed to address this objective. With large thorium reserves, in the long term, our nuclear reactors are expected to predominantly use thorium as fuel. The reactor concepts, which need fissile material only initially and subsequently need only thorium, are expected to support long term sustainability to our nuclear power programme. Molten salt breeder reactor development is aimed towards large scale thorium utilisation. These reactors are being designed to operate at high temperatures, to use different kind of fuel, coolants, and energy conversion systems. This involves large number of technological challenges. These challenges are being addressed through well laid out R & D programmes. This article briefly summarises the R & D work being pursued in BARC for these reactors.

Indian High Temperature Reactor (HTR) Programme

Nuclear energy assisted hydrogen production, by splitting water, is a long term sustainable and environmentally benign option for satisfying the ever-increasing energy needs for our rapidly growing transport sector. High efficiency hydrogen production needs process heat at high temperatures. HTRs have potential to supply this heat. Under our HTR programme, a technology demonstrator Compact High Temperature Reactor (CHTR), and a 20 MWth Innovative High Temperature Reactor (IHTR) are under development. For both of these, the associated technologies were initially aimed to get coolant at 1000 °C as exit temperature. Along with the reactor, development of associated hydrogen production process, called Iodine-Sulphur process, was also initiated. In the interim, an estimation showed that the requirement of high temperature (~850 °C) process heat is only about 8% of the overall energy requirement. Rest of the heat is required at ~ 450 °C or less. Considering severe challenges and qualification requirements for nuclear reactors at 1000 °C, it was decided to develop the reactors operating at relatively lower temperatures. For CHTR and IHTR, the coolant exit temperatures were fixed at 550 °C and 665 °C respectively. The high temperature heat at ~ 850 °C was decided to supply through the electrical heaters.

The current version of CHTR is a lead-bismuth eutectic (LBE) alloy cooled, beryllium oxide moderated 5 MWth reactor using SS 316L for structural material and with a refueling period of ~ 5 years. Design variant of this reactor has the potential to serve as source of power in remote locations. This advanced reactor has several inherent passive systems. These include passive core heat removal by natural circulation of LBE and use of high temperature heat pipes. Studies and developments for this version, called CHTR-B are in progress. Components for a lower powered electrically heated technology demonstration facility are being manufactured. The same will be set up to demonstrate integral behavior of the reactor.

IHTR is based on pebble bed fuel configuration with molten fluoride salt as coolant. Initially conceptual design for 600 MWth reactor has been carried out. Design of a 20 MWth reactor for development and demonstration of technologies is in progress. The reactor with co-generation capabilities, will also produce electricity to support plant load and provide power for the heaters engaged in the segment of the hydrogen production process, which need heat at high temperature. Many of the developments carried out for high temperature version of CHTR has applications in IHTR and similar other high temperature applications.

For reactor physics analysis of CHTR and pebble-based configuration for IHTR, computer codes have been developed. For thermal hydraulics of the coolants, experimental and analytical studies have been carried out. LBE engineering loops working at 550 °C and 1000 °C have been successfully operated. As a part of development of metallic materials for high temperature applications for lead-based coolant, Nb-1%Zr-0.1%C alloy has been developed in collaboration with Nuclear Fuel Complex (NFC). NFC also manufactured a thermal hydraulic loop with the new material for studies at 1000 °C. For HTR fuel, technology for TRISO (TRi-ISOtropic) coated particle-based fuel has been developed. Development of other core material like beryllia, carbon-carbon composite etc. has been carried out. Graphite oxidation studies, large scale characterisation of graphite to develop design rules, and development of oxidation resistant coatings have been carried out. Design of the demonstration IHTR is in progress. Development of heat exchangers, pump, instrumentation, and other components for the molten salt environment are in progress. The interface of this reactor with the hydrogen production plant and safety issues due to combined operation are under detailed investigation. Due to use of fluoride salts, many common requirements for IHTR and IMSBR such as structural material, graphite, salt related components, instrumentation, sensors etc. are being developed together. This has resulted in savings in time, effort and cost.

Indian Molten Salt Breeder Reactor (IMSBR):

IMSBR is being developed as an attractive option for large scale thorium utilization. This is a fluid fuel reactor using thorium-based fuel salt. It is feasible to remove intermediate isotope ^{233}Pa, through a bleed system, which then decays to ^{233}U, outside the reactor. In a solid fuel reactor, this advantage is lost, as ^{233}Pa absorbs neutron and finally ^{234}U is formed. Due to the potential for breeding, MSBR is capable of providing sustainability. Besides efficient conversion of thorium into ^{233}U, MSBR has many other advantages including better safety. Initially conceptual design of a large power reactor was carried out with an aim to identify various R&D areas. As it involves large number of new technologies, design of a 5 MWth demonstration IMSBR is being carried out and the required technologies are being developed. This will serve as test bed for salts, materials, reactors systems, instrumentation, reactor physics and chemistry studies. Operation of this demonstration reactor will help in finalizing the design of the large power IMSBR. The fuel is in the form of a continuously circulating molten fluoride salt, which flows through the reactor core containing graphite moderator blocks. The heat gained is transferred to the coolant salt (i.e. secondary side) by means of an intermediate heat exchanger. The coolant salt in turn, transfers the heat to the Super-critical Carbon dioxide Brayton cycle (SCBC) based power generation system via a salt to SC CO_2 heat exchanger. The core vessel and the fuel salt circuit are contained within a nickel lined steel safety vessel. In a postulated event of leakage of fuel salt, it will be retained in this vessel in a subcritical configuration, while being cooled by passive means.

The reactor physics analysis of fuel circulating IMSBR needs closely coupled neutron transport and CFD codes with capability to account for online reprocessing. Existing computer codes are being modified and new codes are under development to model the neutronic behavior of such reactors. A 3D kinetics code with fuel salt flow and heat transfer model has been developed. Code is also being developed to model refueling and reprocessing aspects of the reactor. Developed codes have been validated against the experimental data from literature. To understand chemistry of fuel and coolant salts, studies such as thermo physical properties evaluation, solubility of fuel, fission products, structural material etc. are in progress. Purification facility for coolant salt has been set up and similar facility is planned for fuel salt. For handling of molten fluoride salts, inert gas glove boxes have been setup. Facilities for production of ThF_4 and UF_4 have been setup. The reactor needs ^7Li based fluoride salts. The development for the same is in progress. An indigenous Ni based alloy, which is compatible to molten fluoride salts, has been developed in collaboration with Mishra Dhatu Nigam Ltd. (MIDHANI). It's scaled up production and fabrication of engineering shapes is in progress. R & D is in progress for development of high density isotropic nuclear grade graphite. Design and technology development for equipment such as pumps, valves, flow meter, dump tanks, intermediate heat exchanger, salt-CO_2 heat exchanger etc. are in progress. Design and studies are also in progress for components of SCBC. Instrumentation and sensors are also under development for molten salt environment. Computational modelling of molten fluoride salts using molecular dynamics is also in progress. Safety studies, batch mode offline reprocessing studies without requiring cooling of fuel salt, studies for reactor control, remote inspection, and qualification of new materials to meet codal design requirements are initiated. It is planned to demonstrate all the major equipment's and systems of the demonstration reactor in full scale under actual operating conditions from temperature and salt chemistry point of view. A dedicated Molten Salt Breeder Reactor Development Facility (MSBRDF) is being designed for setting up at Visakhapatnam for this purpose. Pre-project activities for the same are in progress.

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Book Review

Climate Change and Energy Options for a Sustainable Future

Authors : Dinesh Kumar Srivastava and V S Ramamurthy

Publisher : World Scientific Publishing Co. Pte.Ltd., Singapore

In a recently conducted opinion poll done by UNDP and Oxford University covering about 1.2 million people from 50 countries that represent 56 % of world population, almost two third respondents believed that climate change is a global emergency. This realisation has come almost 125 years after Svante August Arrhenius in 1896 for the first time suggested about global warming due to green house effect. Particularly in last two decades or so, there have been good number of books and other publications regarding global warming.

The book, Climate Change and Energy Options for a Sustainable Future authored by Dinesh Kumar Srivastava and V S Ramamurthy , NIAS, Bengaluru and published by World Scientific in 2021 is a comprehensive account of the problem of Climate Change. It starts with an interesting illustration of our beautiful planet Earth and the beauty and the fragility of the life on it. It then gives a historical perspective of the growth and fall of civilisations in the ancient times. It then builds up a narrative on the industrial revolution and how it has changed the world and its people forever and brought the entire life on the Earth on the verge of becoming extinct. It then gives a detailed description of various energy options and finally talks about the urgent actions to be taken to mitigate global warming. The book has been written in a simple story telling style without too much of technical jargon and should be of common interest to professionals, academicians and students in the field of energy, climate change and sociology and even the general public. It can play a pivotal role in igniting the minds of the readers to take an unambiguous stand in support of the efforts being made for mitigation of climate change.

The first three chapters of the book are about the beauty of Mother Earth and how the life on this beautiful Earth is so delicately balanced and interlinked with life of various species. It reminds that rather than being inheritors of the Earth, we are merely its borrowers for our future generations and it is not just our bounden duty but is a condition imposed on us that we preserve everything for the landers - the future generations. This is the essence of the philosophy of sustainable development. The book mentions about the ancient Greek concept of four basic building blocks of universe viz Fire, Earth, Air and Water and surprisingly does not mention the very well known Indian theory of panchatatva or panchabhuta which in addition to the four elements mentioned by the Greeks, dwells on the fifth element, Aakash (sky or space). Similarly, the book gives credit for the origin of the concept of atoms entirely to the Greek philosopher Democritus who predated Dalton (the architect of modern chemistry via the concept of atoms of elements) by 2000 years . Here again there is no reference to the 'Vaisesika Sutra' in which its author Hindu sage Kanada conceptualised at least 2500 years before Dalton that all matter consisted of indestructible particles called 'paramanu'.

The fourth chapter gives an account of development and collapse of civilisations. Major reasons for collapse of civilization being wars, natural disasters, climate change and over exploitation of resources. It explains how nature has over the millennia evolved a scheme of "checks and balances" to keep things under control. It argues that continued survival of an organism or a civilization is decided by what we call as 'carrying capacity' of the environment which is decided by the amount of necessary resources available. It further argues that over-exploitation of resources results in an 'ecological debt' which keeps on accumulating and gets compounded and ultimately leads to the collapse of the civilization. The book very rightly describes industrial revolution (mid 18th century to mid 19th century as the biggest paradigm shift in the history of human civilization which brought about unprecedented population growth and a steep rise in the standard of living and pushed the world civilization towards consumerism. This was followed by the S & T revolution of the 20th century comprising of many technological breakthroughs like nuclear , semiconductor, lasers, genomics etc. This resulted in an unprecedented and very fast increase in concentration of carbon-di-oxide in the atmosphere. We have now reached a point where, if immediate steps to stop and reverse this growth of greenhouse gases, are not taken, our very existence may be at stake. This problem of greenhouse gas emission and global warning are discussed in details in the 5th and 6th chapters.

The next two chapters (7 and 8) discuss the correlation between energy consumption and human development and the energy consumption projections for the current century. They conclude that the world energy consumption rate as compared to the year 2001 is expected to double in 2050 and more than triple by the end of the century. The authors bring out the enormity of the task of providing enough energy for our masses to pull them out of poverty without smothering the planet with global warming. The 9th and 10th chapters give an account of the fossil and the renewable sources of energy with their strengths and weaknesses. The next four chapters (11 to 14) are devoted to nuclear power including nuclear safety and nuclear waste, nuclear fusion and accelerator driven subcritical systems. There is a chapter on health and other applications of nuclear radiation. The sixteenth chapter is on hydrogen including its production, applications and prospects as a fuel. They conclude by saying that hydrogen holds out the promise of storage and supply of very clean energy in the years to come.

In the penultimate chapter 'Summary and Outlook', it is re-emphasized that having depended largely on fossil fuels during the last two centuries , we have already put the world in the risk of life becoming extinct on this only planet known to have life. The biggest challenge before us is to provide enough, reliable and affordable power to all without worsening the already precarious state of the global climate. They very rightly note that the increasing deployment of green energy is a good sign but the pace at which it is being done is not at all enough to limit the rise in temp to 1.5°C as recommended by IPCC for which zero emission by 2050 is essential. The authors while talking about the global energy grid, mention the Indian initiative, 'One Sun One World One grid', which takes advantage of the fact that the Sun is continuously irradiating half of the earth with light and heat. In view of nuclear being one of the most reliable and clean source of plentiful electricity for the entire world for thousands of years, they propose the strategy of coupling the proposed global electricity grid to the nuclear power stations .

The concluding chapter 'Epilogue' is written prophetically, very rightly summarizing the precarious state in which the human greed has put our civilization. How true the words of Mahatma Gandhi, "The earth has enough for everybody's need but not for one man's greed", are proving in this context. They describe how the concept of consumerism has driven us towards manufacturing and marketing more and more and do it even when it is not required. Quoting the World Watch Institute, Washington DC, they describe that about 22 % of the world population today belongs to the consumer class who are characterized by diets of highly processed foods, aspiration for bigger houses and cars, tendency of accumulation of non-essential goods and 'use and throw' culture. This has taken a devastating toll on Earth's water supplies, natural resources and ecosystems. While talking about electricity, 'over consumption' by the western nations in excess of 12000 kWh per person per year, they note that merely one third of that can suffice to provide a Human Development Index of 0.8. While concluding this discussion on role of greed in the predicament that the world finds itself in, they recall the philosophy of not accumulating things unnecessarily, called 'aparigraha', which forms the guiding principle of Vedic, Jain and Thirukkural traditions of India, can rescue the world out of this consumerism and redirect the world civilization towards sustainable development in true sense.

Reviewer : Sh. S.K.Malhotra

Nuclear News Snippets

Why a leading environmentalist changed her mind on nuclear power

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Russia Says Its Nuclear-Powered Space Tug Can Detect, Disable & Shoot-Down Enemy Spacecraft From The Orbit

eurasiantimes.com/russia-says-its-nuclear-powered-space-tug-can-detect-disable-shoot-down-enemy-spacecraft-from-the-orbit

How nuclear tech helps China's COVID-19 battle

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Nuclear-powered space crafts are on the way:

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Revolutionary Micro Nuclear Reactors Will Run on Waste

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Nuclear could help Spain reach net-zero goal, says IEA
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UK energy secretary stresses nuclear's role in decarbonisation
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US Climate Advisor sees 'essential' need to retain nuclear units
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Coal demand to boost CO2 emissions in 2021, says IEA
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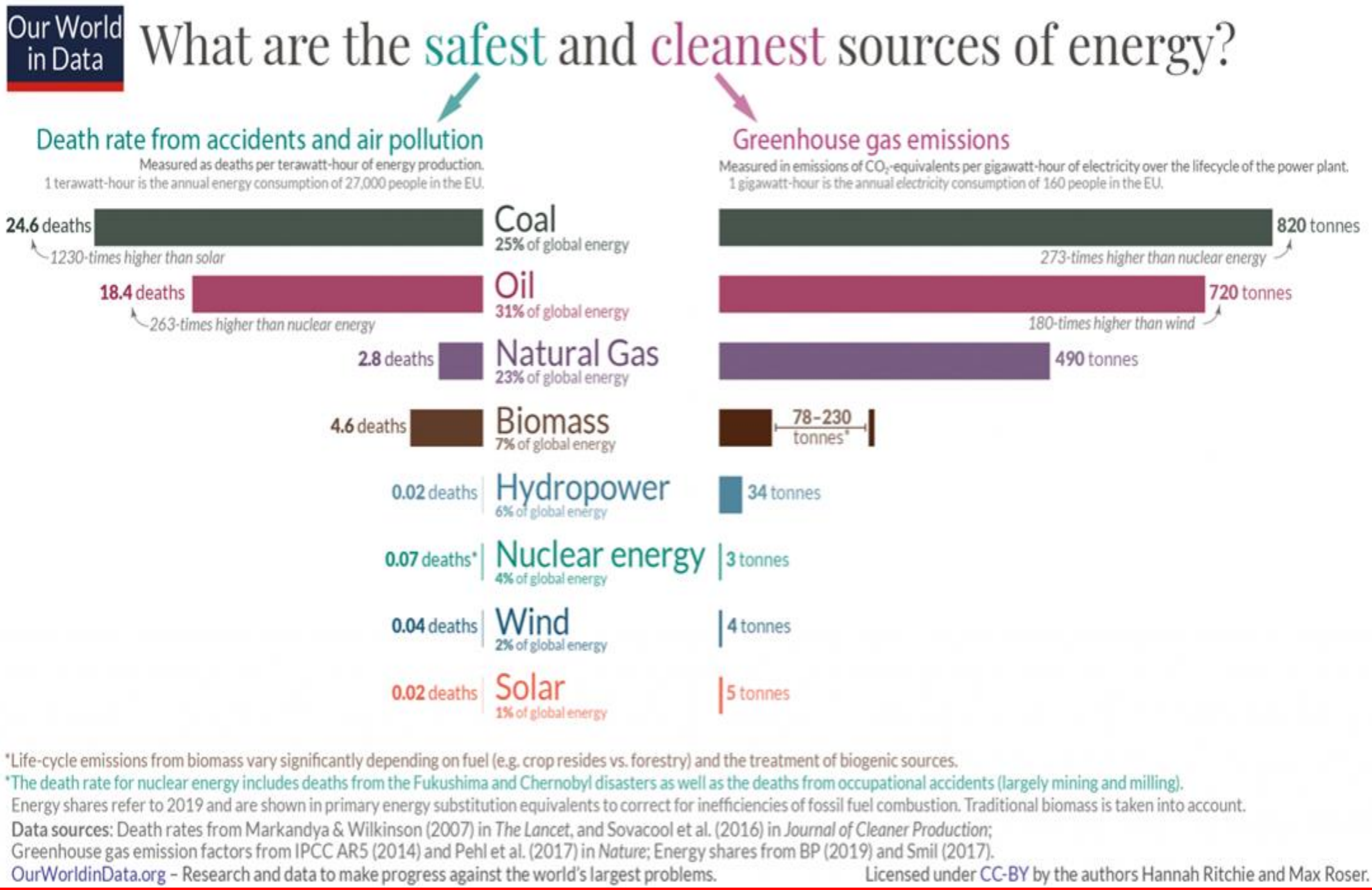
Compiled by Sh. S.K.Malhotra

How many people has nuclear energy saved?

When people discuss the safety of nuclear energy, they often focus on the number of deaths it has caused. But as per the chart given below, nuclear is one of the safest and cleanest energy sources per unit of energy. It results in fewer deaths than coal, oil or gas, and is comparable to modern renewables such as solar or wind. By this reasoning, one should perhaps turn this question on its head and ask: "How many lives has nuclear energy saved?", or "How many lives could have been saved if countries had not abandoned it?"

In the wake of the 2011 Fukushima nuclear disaster, Germany announced plans to phase out nuclear power generation: over the period from 2011 to 2017 it shut down 10 of its 17 nuclear facilities, and plans to close the remaining reactors in 2022. Because nuclear is safer than its main alternatives this policy decision cost lives.

Replacing nuclear energy with fossil fuels kills people. This is likely to be the case in the recent example of Germany. Most of Germany's energy deficit from scrapping nuclear was filled by increased coal production – which is, the most polluting source with the largest health impacts. Analysis by Stephen



Source: https://ourworldindata.org/nuclear-energy?country=#how-many-people-has-nuclear-energy-saved

Jarvis et al. (The Private and External Costs of Germany's Nuclear Phase-Out (No. w 26598). National Bureau of Economic Research) estimates that Germany's nuclear phase-out has come at the cost of more than 1,100 additional deaths each year as a result of air pollution. Germany's plan to make its energy systems safer has done exactly the opposite.

In a study published in *Environmental Science and Technology* (47(9), 4889-4895), Pushker Kharecha and James Hansen aimed to answer the question 'how many lives has nuclear power saved?'. They analysed how many more people would have died over the period from 1971 to 2009 if nuclear energy had been replaced by fossil fuels. The death toll would have depended on the mix of fossil fuels used to replace nuclear – more would have died if more coal was used than oil or gas – but they estimate that nuclear power has globally saved about two million lives.

Compiled by Dr A.RamaRao

INS Round up

1. INS Endorses Nuclear for Climate Initiative

Indian Nuclear Society along with more than **100 other nuclear societies around the globe has called for world leaders to "follow the science" and recognise that nuclear energy output must at least double by 2050 to meet global net-zero targets. The call comes ahead of the 26th UN Climate Change Conference of the Parties (COP26) being held in Glasgow from November 1-12 this year.** They are calling on UK Prime Minister Boris Johnson, COP26 President Alok Sharma and United Nations Framework Convention on Climate Change (UNFCC) Executive Secretary Patricia Espinosa to acknowledge nuclear's crucial position alongside renewables in attaining net-zero carbon emissions by 2050.

INS also endorsed the position paper **'Net Zero Needs Nuclear'** brought out in February 2021 by **'Nuclear for Climate'** - a grassroots initiative gathering nuclear professionals and scientists from over 150 associations. The paper outlines the scientific justification behind why net-zero needs nuclear and calls on all those involved at COP26 to take a science-led and technology-neutral approach to energy policy and financing.

2. Fourth INS Webinar

The 4th INS Webinar titled "**A Decade after Fukushima Daiichi Nuclear Reactor Accident"** was delivered by Prof. V. S, Ramamurthy Emeritus Professor, NIAS and Former Secretary, DST on May 11, 2021. It was followed by a lively Q/A session. Dr A.P.Tiwari and Dr A. Rama Rao were the convenor / co-convenor of the Webinar

3. Rich tributes paid by INS to Late Dr. Srikumar Banerjee

Indian Nuclear Society convened a virtual meeting on May 26, 2021 to pay tributes to Late Dr. Srikumar Banerjee, an esteemed member of the INS family who left for his heavenly abode in the wee hours of May 23, 2021. Dr, G.K. Dey, through a presentation recalled the R & D work carried out by Dr. Banerjee in the field of Metallurgy and Material Science. Dr. R.B. Grover recalled the rich contributions of Dr. Banerjee as Chairman, AEC and as Chancellor, HBNI. Dr. Anil Kakodkar reminisced his close association with Dr. Banerjee and his immense contributions to nuclear power programme. Shri S.K.Mehta, President, INS, Dr. V.K. Manchanda, Vice President INS, Dr P.R.V.Rao, VC, HBNI, Shri S. A, Bhardwaj, Former Chairman AERB, Dr. A. K. Suri, Former Director, Materials Group, BARC and a large number of INS members and former colleagues of Dr. Banerjee also recalled their interactions with him. In the end, Shri S.K. Malhotra, Secretary, INS read out the condolence message that was sent to Mrs. Ranjana Banerjee, wife of Dr. Srikumar Banerjee. The meeting ended with observance of two minutes silence as a mark of respect to the departed soul. Dr A.P.Tiwari was the convenor of the Webinar.

4. Programmes organised by other institutions to disseminate information related to Science and Technology where INS members actively participated

4.1 Dr Anil Kakodkar was the Chief Guest and Key note speaker on the Anniversary Celebrations of Webinar Series of Indian Society of Analytical Scientists on 3rd July, 2021. He talked on " Science and Technology Approach for Atmanirbhar (Self reliant) Bharat. He mentioned several strides DAE / BARC has made towards accomplishing self reliance in Nuclear Science and Technology. Highlight of the program was a lively Q/A session.

4.2 Dr V.K. Manchanda, Vice President, INS delivered a webinar on 26th June, 2021 under the auspices of the Indian Society of Analytical Scientists. He elaborated on some developments in Nuclear Fuel Cycle as a part of his talk on " Perspectives on Separation Science and Technology"

5. New Members of INS (2021)

The INS Family welcomes 37 new members who have joined so far in 2021. Twenty nine of these are from DAE fraternity, two are from AERB, two are from Academic Institutes and four are from industry.

Compiled by Sh S.K.Malhotra

"Our virtues and our failures are inseparable, like force and matter. When they separate, man is no more"

- Nikola Tesla

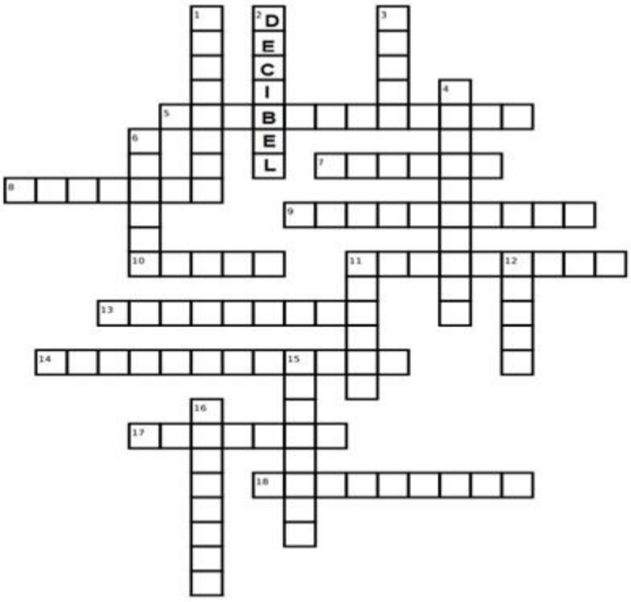
"Research is to see what everybody else has seen, and to think what nobody else has thought"

- Albert Szent-Györgyi

"In science the credit goes to the man who convinces the world, not to the man to whom the idea first occurs."

- Sir William Osler

Crossword Puzzle



Down:
1. Force that causes body to float
2. Unit of measurement which is 1/10th of bel
3. Symbol of summation
4. Electrical insulator that can be polarised
6. Vision defect in eye
11. __________ of force on a body causes reaction
12. Law of elastic limit
15. Other name for aircraft wing
16. Component storing electrical energy in the form of magnetic energy

Across:
5. Radioactive method of determining age of organic objects
7. Pair of equal forces
8. Measure of randomness in energy
9. Bulk heat transfer in fluids
10. Operator of a vector product
11. Non crystalline solid
13. Heat beyond boiling point without boiling
14. Heat engine operating in reverse.
17. Rope is in _____________ when subjected to pull force
18. Material that permit free flow of electrons

Contributed by Dr A.RamaRao

Solution to the Cross word puzzle appeared in INS NL May ,2021 (Vol 21 Issue 2)

Across
2. SCRAM
6. MODERATOR
7. UCIL
10. NEUTRINO
11. ALARA
13. TBP
14. HELIUM
15. SPIN
16. CRITICAL
17. CURIE
18. RBMK

Down
1. BARN
3. COOLANT
4. MDU
5. BORON
8. IAEA
9. GRAPHITE
11. ATOM
12. ACTINIDES
13. THORIUM

Congratulations to the winners

1. Dr S.G.Marathe, Retired BARC
2. Mrs Mudita Singh, TAPS 3&4, NPCIL
3. Mr Amit Sen , AERB
4. Dr S.P.Panda , NPCIL
5. Prof. A.N.Garg, Amity Univ., NOIDA

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